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Electrical caddy for postal distribution energy flow analysis.

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Electrical caddy for postal distribution energy flow analysis.

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1. Introduction

The idea of this prototype begins with the necessity of transporting heavy loads. The idea was to create a caddy capable of delivering safe and easy charges in urban areas. The project emerged to help the postal service and provide them a reliable solution. The problem to transport these payloads over the city is indeed difficult for the postal workers. A caddy equipped with several compartments would be suitable to solve this problem. However, the key point was the difficulties to drive a normal caddy with heavy payloads. Implementing electric motor on the caddy could be a solution to carry these payloads.

The German company “Expresso” (with experience about this kind of electric caddy) created an electric caddy following the specifications of the postal companies. This kind of caddy is using in this moment by the German postal service. The Belgium and British postal service are going to use this caddy also in a future. Solutions available in this moment cannot be comparable with the efficient propose we have mentioned, an electrical caddy which in addition, is more ecological.

This leads to the NEPH project for the creation of an electric caddy.

1.1. NEPH project

1.1.1. Introduction

Everybody knows about the postman work. They deliver our mail to every place. To reach the place in which the mail should be delivered they use some different means, either by foot or by means of vehicles. Inside a city, the mail is divided into offices which each one owns to an area or some areas. To deliver in these areas, they use different kind of vehicles.

In Europe, electric bicycles started in the 1990's a great impact in the society, for its not necessity of being a sportive person, for being less contaminant than other means of transport, so why do not postman use electric vehicles on their trips in the urban areas? With this aim, the Eureka project E!3364 came up called New Electric Postman Helper (NEPH). This project deals with the study and development of innovative electric power trains systems that will be integrated in personal mobility devices for helping postmen with their deliveries in urban areas. The project is gathering seven post companies of their respective European countries; the consortium includes a battery and a motor system manufacturer in charge of the development of the technology for the vehicles and the Vrije Universiteit Brussels (VUB) in charge, among other tasks, of the tests and evaluations of the prototypes.

The postal requirements correspond to very high levels for performance, reliability and service. The objectives of this European project can be summarized as follows:

- Improvement of electric and mechanical reliability.
- New motor system technology associated with advanced batteries (NiMH and Liion).
- Intelligent energy management in order to have an efficient use of the battery (whatever the technology).
- Cost decrease due to modular concepts.
- Innovative design in order to facilitate the setting up of associated services required by postal operators.

The NEPH project will focus on 3 main parts of the power train system: battery system, electric motor system and human-machine interface.

1.2. Targets of the project

Our first aim is to obtain the differences in consumption on different types of undergrounds and payloads. Nevertheless, the main aim of the project will be to obtain a simulation model to estimate the energy consumption of the caddy.
Introducing several parameters:

- Weight.
- Number of stops.
- Height difference.
- Different types of Undergrounds.

The comparison between the real consumption and the estimation will give us a prediction of the real consumption of the caddy depending on different situations. To be successful with our simulation model, it must be as realistic as possible.

2. Electric Caddy for postal usage

2.1. Explanation of the caddy

Our caddy is equipped with a sensor in its grip to drive it, which is patented by Expresso and offer an easy handling of the caddy even under heavy loads. With two electric motors (one on each wheel) connected to each sensor to control the direction. Always running through the man-machine interface, the caddy is locked at the time you release the sensor as a security system. The responsible for the control is the drive unit.

The caddy must accomplish with the requirements set by the postal services. The special features are shown as follow:

- Rain protection required.
- Security features.
- User ergonomics.
- Size of the post bags or boxes.
- Maximum payload: 150 Kg.
- Maximum speed: 6 Km/h.
- Power required: 210W motor.
- Equipped with two motors.

The caddy is formed by different electric parts: Sensor, controller, two motors and the batteries. It only works with a special human interaction mode. There exist two sensors for each hand connected to the controller. To put our caddy into operation we need to press both sensors at the same time. Leaving them free, we will stop it.

The driver sends the signal to each motor and the output is based on the signals of the sensors.

2.2. Electric drive train

The drive train of an electric caddy consists of a controller or control unit, a battery, two motors and driving sensors.
The integrated control unit controls all the electric functions between motor, battery and driving sensors. It works as the on/off operation mode of the system. Once the system is working, the driver can start out riding the caddy by pushing and by using the sensors. Once the throttle is turned on, the controller will regulate the electrical power to the motor.
When it stops pushing the sensors, the motor is automatically turned off and the wheels are blocked.

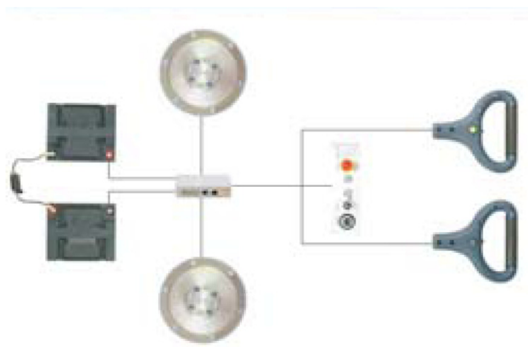


Figure 1.[[1]]

2.3. Batteries

A battery is a device that converts chemical energy directly to electrical energy. The batteries implemented on the caddy are gel-cell batteries. This kind of batteries is one of the most successful electro-mechanical systems ever developed. [2]

There are three types of lead acid batteries widely used: batteries with flooded or excess electrolyte, low-maintenance lead acid batteries with a large excess of electrolyte and batteries with immobilized electrolyte and pressure-sensitive valve [].Our caddy uses the second type. Lead acid batteries typically have coulombic efficiencies of 85% and energy efficiencies in the order of 70%.

The weight of the batteries is not really important due to the fact that the global weight of the caddy is significantly higher. The control system, drive motors, and displays of the caddy are energized by two gel-cell batteries. The compartment for the batteries designed at the bottom of the caddy (see Fig. 7).

In a normal use of the caddy, battery life is about 1000 charge/discharge cycles. The life is about 3 years. Recharging should be done on a daily basis, because higher discharge rates also reduce the number of possible charging cycles.
Damaged batteries exhibit reduced power and can no longer hold a full charge or can possibly not be charged at all.

Figure 2

The electrical energy content of a battery expressed in ampere-hours (Ah) is called capacity. But the capacity of the batteries depends on the current consumption of the drive train. The Peukert's equation is a formula that shows how the available capacity of a battery changes according to the rate of discharge. The capacity of a battery is expressed in Ampere–hours (Ah), but it turns out that the simple formula of current times hours does not accurately represent the situation.[Models of energy sources publication]

$$C = I^k * time$$

Equation 1

The Peukert's affects to the battery decreasing the battery's capacity when the rate is increased. This means that the available time in which the battery is discharge will be slightly less [11]. The following points explain the characteristics of the batteries of the caddy.

2.3.1. Characteristics of the caddy batteries

- Maintenance-free lead gel-cell batteries 2 x 12V 50 Ah
- Main fuse 80 A

- Electronically controlled charging unit 8 A
- Weight of the batteries 27 Kg

2.3.2. Batteries technologies

The Ragone Plot shows the relation between the power density (Wh/kg) and the energy density (Wh/kg), in this example with different kinds of batteries there exist a sensible difference.

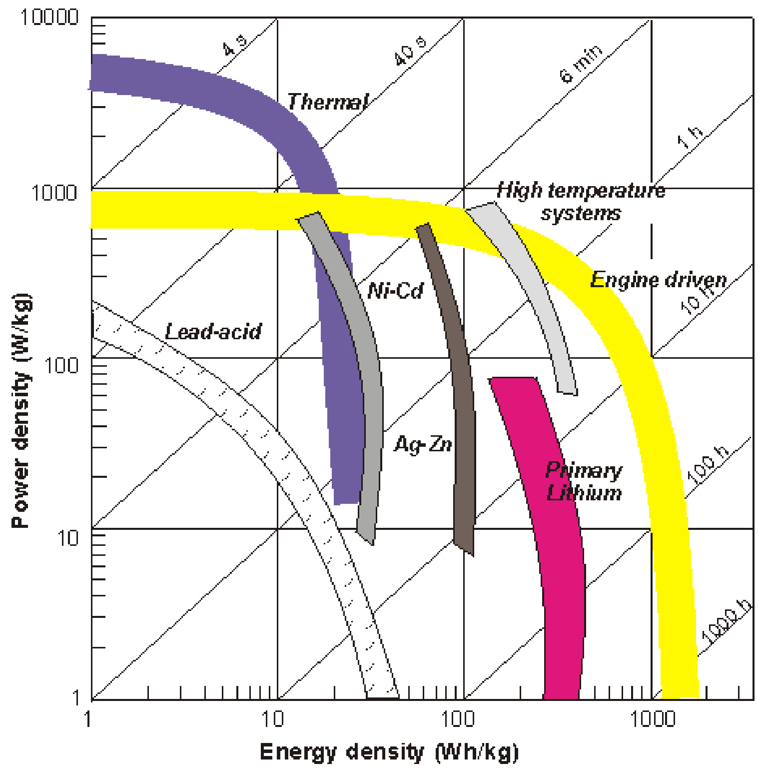


Figure 3.[2].

In this graphic we can see the differences between Lead-acid batteries and other usual kinds of batteries. The range of the quality of these batteries is really extensive but most of the rest of batteries have a better curve on the plot. As we have explained before, the weight is not an important factor to select out the kind of batteries due to the weight of the caddy is much bigger than the batteries.

2.4. Motor system

The motor system of the caddy consists of two electric motors (one in each wheel). The caddy uses a **brushless** direct drive wheel system. The brushless (DC) motor is a synchronous electric motor which is powered by direct-current electricity (DC) and it has an electronically controlled commutation system, instead of a mechanical commutation system based on brushes. In these motors, the maintenance is almost free due to the fact that there is not any contact with the rotate commutator.

2.4.1. Electrical motor used on the caddy

The brushless direct drive wheel motors used on the caddy have high torques, these motors are highly versatile and reliable. The control of the motor is electronic therefore the operation is really precisely. This kind of motors used single or in pairs are very useful on the transport systems like the caddy.
In fact if the motor is in pairs the electronic control use the CAN- bus to communicate each other. The motor is sturdy and virtually maintenance-free by the lack of mechanical contact. The caddy is braking also electronically so there is no wear.

2.4.2. Advantages of Wheel Motors

1. High torque.
2. Maintenance free (he braking is electronically and there is no mechanical contact).
3. Compact.
4. Functional.
5. Versatile.
6. Optional brake (it can be automatically and manual mode).

Figure 4
RN-EC with optional tyre equipment

2.5. Sensors of the caddy

The caddy is fitted with sensor handles that include a hand detection system. Together with the control system, this allows the drive motors to be activated only if the operator has grasped both sensor handles firmly. The sensor handles perform two different tasks: Figure 5

1. The safety brake is released only if both hands are placed around the rubber grips. If both hands are removed from the grips, the safety brake is applied automatically.
2. The handles detect the direction of movement required by the operator, and transfer this information to the drive units.

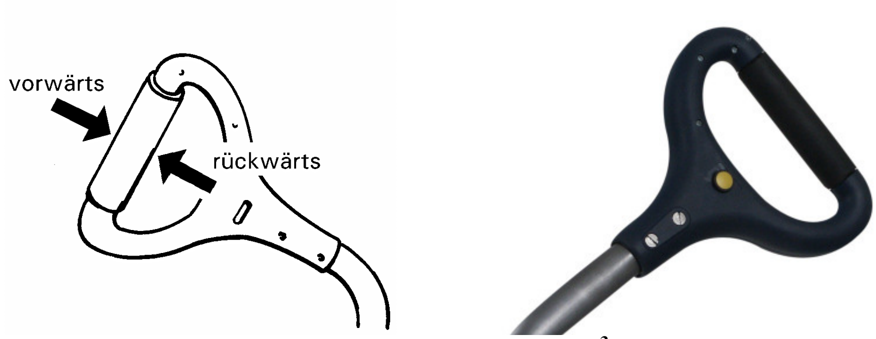


Figure 5. Sensor handles [3]

Forwards/reverse movements are determined by pushing or pulling the sensor handles. If the same forces is applied to the both handles, movement is along a straight line. If different forces are applied to the handles, the trolley moves in a curve. Turning on the spot is possible, if one handle is pulled while the other is pushed.

Using the handles in the same way as if there was not power assistance, the driver wants to push/pull the cart by yourself. However, instead of pushing hard against the grips of the sensor handles, operator only needs to apply slight pressure.

2.6. Advantages and disadvantages of the electric caddy

First of all, the caddy is a working tool of the postal service. There are several advantages but the most important one is the ability to carry large amounts of weights without any effort. Another advantage is the easy handling to drive in different kinds of underground and climatic situations. The behavior of the caddy has been correct in every tests done in different situations. The possibility of moving in high slopes, large distances and spots become it in a very adaptable tool.

Despite all these advantages, there are some disadvantages. There is not possibility to move the caddy without power, because the wheels are blocked when the drive system stop to send signal to the motors. Another disadvantage is that the driving becomes increasingly difficult with high weights.

3. Analysis of the energy consumption

3.1. Mechanical power analysis

At the beginning of the project the comparation was based on different tests to obtain results about the behavior and the consumption of the caddy. The tests made in several kinds of undergrounds and increasing the weight in each test to compare the consumption by graphics. Measuring the voltage (directly from the batteries) and the current (by a LEM) to achieve the power and the energy consumption of the caddy. The different types of undergrounds show different consumptions.

3.1.1. Influence of the payload and underground types

The different weights show different graphics in the energy consumption, it depends on the type of underground. In the next graph we can see the difference between flat concrete (laboratory), sidewalk, fine gravel and the asphalt.

Graphics show how on the fine gravel the consumption is higher, and how the consumption increase with high weights. In fact, except on concrete flat when the weight is maximum the consumption is similar in every type of undergrounds.

The weight is growing up from 20 kg to 60 by steps of 20 kg and from 60 to 150 kg by steps of 30 kg. The different types of undergrounds are as follow:

- On flat concrete (inside of the laboratory).
- On the grass.

- On the asphalt.
- On fine gravel.
- On the side walk.

The first results show differences in the consumption depending on the weight and surfaces. All of these tests have been essentials to obtain the simulation model to estimate the consumption.

The consumption depends on the underground type and weight. Nevertheless, the most suitable method to prove our assumptions is through graphics.

3.1.2. Ways of driving

Another important and difficult evaluated parameter is the way of driving. The consumption is higher in a sportive driving than a smooth driving. Some studies show an increase of 29% about the consumption in a sportive way, as we showed in our studies that we made according to this issue.

The test measured with digital and portable oscilloscope shows a large pick at the end of each stop. This way of driving produces this extra consumption when you give up sharply the caddy.

The caddy has to consume energy to brake the wheels. In fact, the electric motor has to stop de caddy in an electronic way according to the Brusheless's principles.[]

3.2. Electrical power analysis

3.2.1. Drive train global efficiency

The efficiency is the useful output power divided by the total electrical power consumed. In case to achieve the torque on the wheels, the best way to bring off the efficiency of the drive train would be compare the energy from the batteries and divide by the energy on the wheels. However, is only possible obtaining the speed of the wheels by the CAN-bus of the caddy.
Deriving the speed we obtain the acceleration of the caddy, with the weight of the caddy and the acceleration we already have the definition of force. However, this is not the real force because there are other factors which affect to the total force.
The rolling resistance force and the potential force cause effects on the total force. These forces go against to the summation force.

The total force (real force) is the difference between the summation forces minus the potential and rolling resistance forces. The integral of the total force on the time domain is the drive train total energy. Dividing this force by the energy bring off the batteries we have the drive train global total efficiency.

By the next equations is easier to understand previous explanations:

$$\sum F = M.a = Ft - Fr - F\alpha \qquad \text{Equation 3.1}$$

$$Fr = M.g.c_{rr} \qquad \text{Equation 2.2}$$

$$F\alpha = M.g.\sin(\alpha) \qquad \text{Equation 3.3}$$

$$Ft = M.a - Fr - F\alpha \qquad \text{Equation 3.4}$$

$$Pt = Ft.v \qquad \text{Equation 3.5}$$

$$Et_{wheels} = \int_0^t Ptdt \qquad \text{Equation 3.6}$$

$$Et_{batteries} = \int_0^t V.idt \qquad \text{Equation 3.7}$$

$$\eta_{drivetrain} = \frac{Et_{wheels}}{Et_{batteries}} \qquad \text{Equation 3.8}$$

c_{rr} = Rolling resistance coefficient.
Fr = Rolling resistance force.
$F\alpha$ =Potential force.
Ft = Total force.
Pt = Total power.
Et_{wheels} = Total energy.
$Et_{batteries}$ = Total energy from the batteries.
$\eta_{drivetrain}$ = Drive train global efficiency.

4. Measurements on the prototype

4.1. Procedure of measurement

4.1.1. Procedure of each test

Every test has been realized at the same way. The reason is obtain as data as possible to compare. If the procedure would not be the same, it would be impossible to compare the different consumptions. Each one depends on the underground type.

The procedure of the tests has been made thinking about the postal service routes. Each test has the same procedure characteristics:

- 40 stops and go.
- 10 meters between each stop and go (400 meters).
- 10 seconds of waiting by stop.

The way of the test is always with the same procedure of starts and stops. The follow points explain the way of the tests.

1. Start the caddy. After 10 meters stop and wait 10 seconds.
2. After wait 10 seconds, start the caddy again and stop after 10 meters.
3. Go back the caddy the necessary to return the caddy.
4. Start the caddy. After 10 meters stop and wait 10 seconds.
5. Start the caddy and after 10 meters return the caddy at the same time it is finishing the 10 meters.

The reason of the 10 seconds between each stop and go is due to the fact that it is the time that the user needs for realize the job. Furthermore, the distance of 10 meters has been selected as an approximate distance between each selected as an approximate distance between each house.

Figure 6. Procedure test.

4.1.2. Measurement board

The data collection at first consisted on obtaining the current and the voltage. On the one hand, the voltage is obtained directly from the batteries and on the other hand, the current is achieved by a LEM. This LEM needs an extra battery to work.

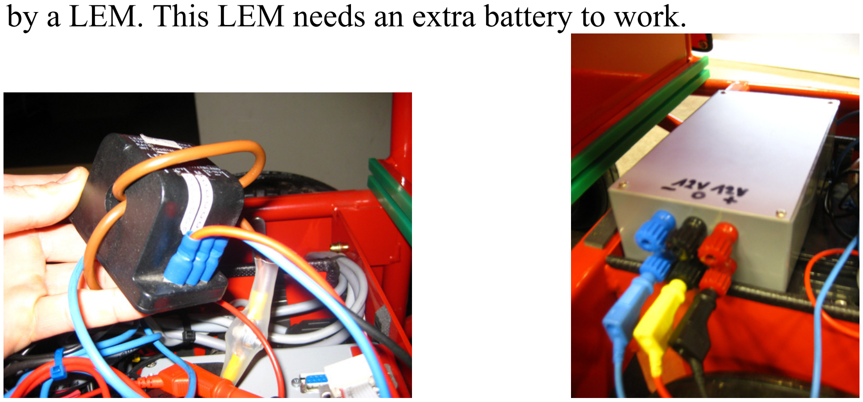


Figure 7. LEM and Extra battery for the LEM.

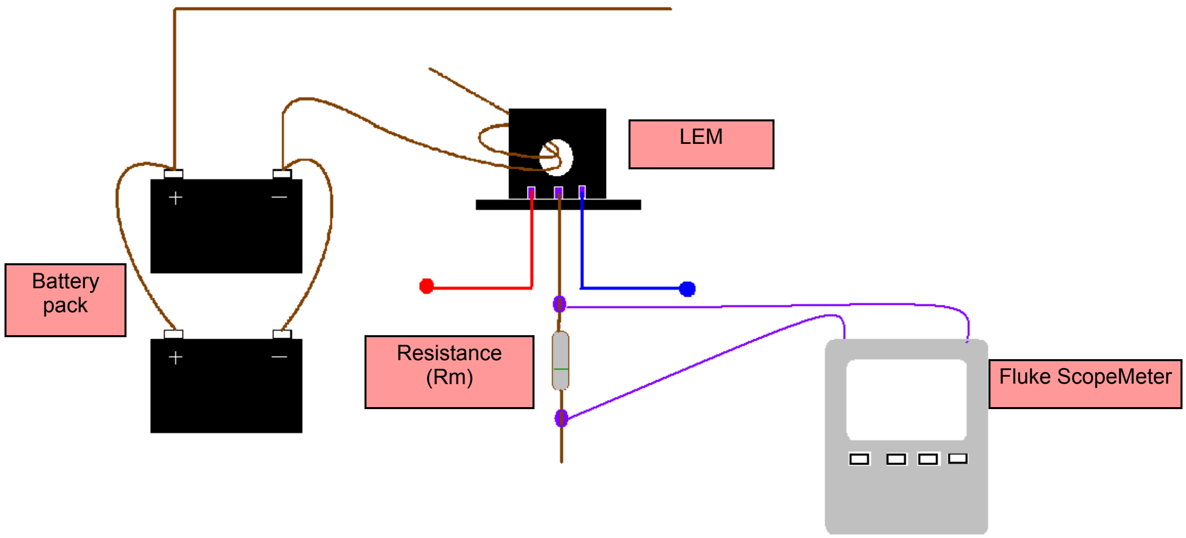


Figure 8. Schema of the circuit

4.1.3. Measurement protocol

These data are collected on the oscilloscope and after each test the oscilloscope is connected to the computer to download the data. We can track these data to obtain the current, power and finally the energy. In spite of the data, we can see the current and voltage signal on the oscilloscope and on the computer to know where the picks of the consumption are located.

Figure 9.Fluke ScopeMeter.

The Fluke scope has two channels, each one connected to their respective cable (current and voltage). To obtain the current we have to do a transform of the voltage measured by the LEM using an equation.

The cable crosses two times the LEM inducing a current (Im), this current pass through the resistance (Rm)and in this way, obtain the voltage (Um).

The conversion to achieve the current is made about a few simple equations.

$$Um = \frac{Rm * Ib * 2}{1000}$$ **Equation 3**

$$Um = \frac{99 * Ib * 2}{1000}$$ **Equation 4**

Finally, the equation to obtain the current consumed from the batteries is as follow:

$$Ib = \frac{1000 * Um}{2 * 99}$$

Equation 5

4.1.4. How to use the Fluke scope

The connections to obtain the voltage and the current are on top of the scope, each one with its respective cable. The scale of the scope needs to be set and the same for the time of measurement to watching on the screen both channels.
Once calibrated the scope, we can start the procedure to make the tests.

4.1.5. Starting the recording

Starting on the Fluke scope analyzer: To make a new recording, the next steps have to be followed:

- Switch on the Fluke scope analyser.
- Push the *Recorder* button.
- Select the sub-menu *Scope Record and starting of a recording* using theright key and the enter key (the button in the centre of the navigation keys).
- In the *Start* and *End* field, press enter key to define the starting date and time of the new recording. Use the up and down key to increase or decrease the value and the right key to move to an adjacent item.
- In the *Period* field select the period of time (1s, 5s, 10s, 1mn, 2mn, 5mn, 10mn, 15mn) which the integration of the measurements will be recorded.

4.1.6. Stop the recording

The recording can be stopped in any moment pressing the hand button on the right side of the screen in the *Recording* menu.

Sending the data to a computer

1. Use the USB cable to connect the Fluke scope to the computer.
2. Switch on the Fluke scope.
3. Open the program in the computer. (Fluke view).
4. Select the file you want to transfer and wait until it finishes.
5. Save the file in the computer. You can choose between two extensions: .csv and .dvb.

4.1.7. Delete a recording

Select the delete submenu to delete a file to the Fluke scope. Go up and down with the keys until the file you want to delete and press the enter key.

4.1.8. Get the data

The batteries have been charged, each one more than only once. Some of the data do not have to be kept, but it has to be rejected. This is because, sometimes the charge could not finish completely (or not completely recorded with the Fluke scope power analyser) and the battery was not be completely depleted. The average of all the correctly measured and full charges will be made. Now, one has one result for every battery and it is now possible to make some calculations as well as some comparisons.
In the configuration menu of the Fluke scope meter there are a lot of different measurements and results that can be recorded. The required results are power and energy, expressed in watt and in watt/hour respectively. Then, a plot is made with Excell program (Figure 7).

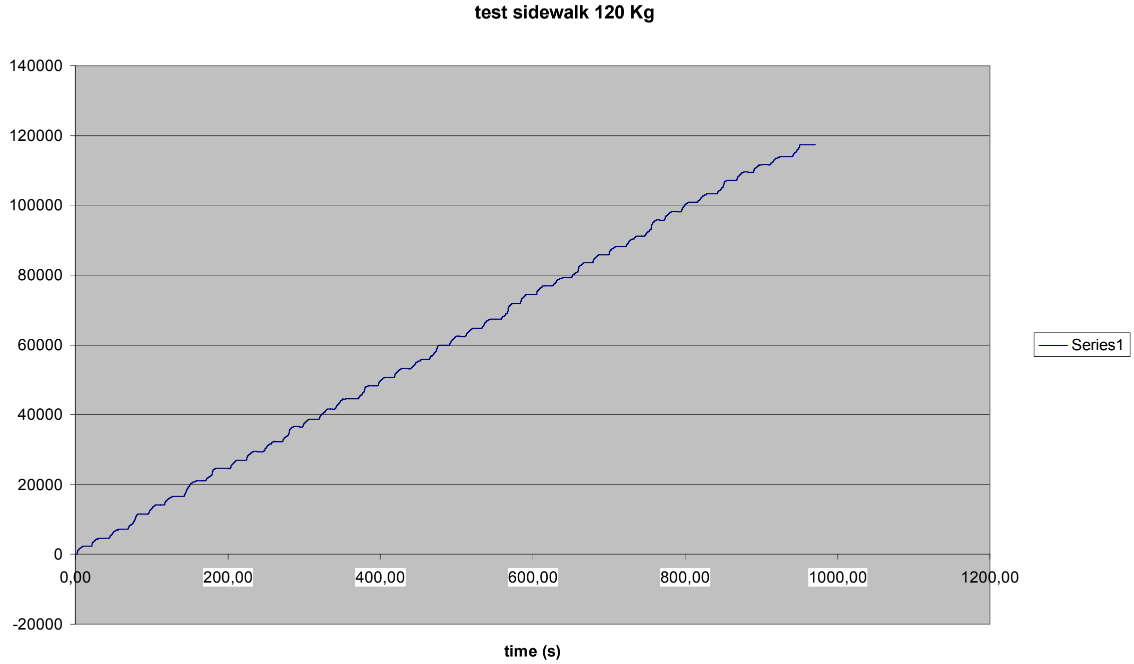


Figure 10.plot of the Energy (Watt/sec.) and time (seconds).

With these plots, the energy consumption by time(s), we can see the watt-hour consumed for every test. This is an example plot of one test.

min	max	Voltage	Time	min	max	avg+calc	Current	Time	power	energy
2,58E+01	2,60E+01	25,9	1,24E+00	0,00E+00	3,20E-01	0,808081	0,80834	1,24E+00	20,94	0,21
2,58E+01	2,60E+01	25,9	1,28E+00	1,60E-01	4,00E-01	1,414141	1,41441	1,28E+00	36,63	1,36
2,58E+01	2,60E+01	25,9	1,32E+00	2,40E-01	4,80E-01	1,818182	1,81846	1,32E+00	47,1	3,04
2,58E+01	2,58E+01	25,8	1,36E+00	2,40E-01	5,60E-01	2,020202	2,02049	1,36E+00	52,13	5,02
2,58E+01	2,58E+01	25,8	1,40E+00	4,00E-01	5,60E-01	2,424242	2,42454	1,40E+00	62,55	7,32
2,58E+01	2,58E+01	25,8	1,44E+00	4,80E-01	5,60E-01	2,626263	2,62656	1,44E+00	67,77	9,92
2,58E+01	2,58E+01	25,8	1,48E+00	4,80E-01	6,40E-01	2,828283	2,82859	1,48E+00	72,98	12,74
2,58E+01	2,58E+01	25,8	1,52E+00	4,80E-01	6,40E-01	2,828283	2,8286	1,52E+00	72,98	15,66
2,58E+01	2,58E+01	25,8	1,56E+00	4,80E-01	6,40E-01	2,828283	2,82861	1,56E+00	72,98	18,58
2,58E+01	2,58E+01	25,8	1,60E+00	4,80E-01	6,40E-01	2,828283	2,82862	1,60E+00	72,98	21,5
2,58E+01	2,60E+01	25,9	1,64E+00	1,60E-01	5,60E-01	1,818182	1,81853	1,64E+00	47,1	23,9
2,58E+01	2,60E+01	25,9	1,68E+00	8,00E-02	3,20E-01	1,010101	1,01045	1,68E+00	26,17	25,36
2,58E+01	2,60E+01	25,9	1,72E+00	8,00E-02	4,80E-01	1,414141	1,4145	1,72E+00	36,64	26,62
2,58E+01	2,58E+01	25,8	1,76E+00	4,00E-01	1,04E+00	3,636364	3,63673	1,76E+00	93,83	29,23
2,54E+01	2,58E+01	25,6	1,80E+00	8,00E-01	1,68E+00	6,262626	6,263	1,80E+00	160,33	34,31
2,54E+01	2,58E+01	25,6	1,84E+00	1,44E+00	2,32E+00	9,494949	9,49534	1,84E+00	243,08	42,38
2,52E+01	2,56E+01	25,4	1,88E+00	1,84E+00	3,12E+00	12,52525	12,52565	1,88E+00	318,15	53,6
2,52E+01	2,54E+01	25,3	1,92E+00	2,64E+00	4,00E+00	16,76768	16,76808	1,92E+00	424,23	68,45
2,50E+01	2,54E+01	25,2	1,96E+00	3,44E+00	4,88E+00	21,0101	21,01051	1,96E+00	529,46	87,53

Table 1.Excel data download from Fluke Scope.

4.2. First results

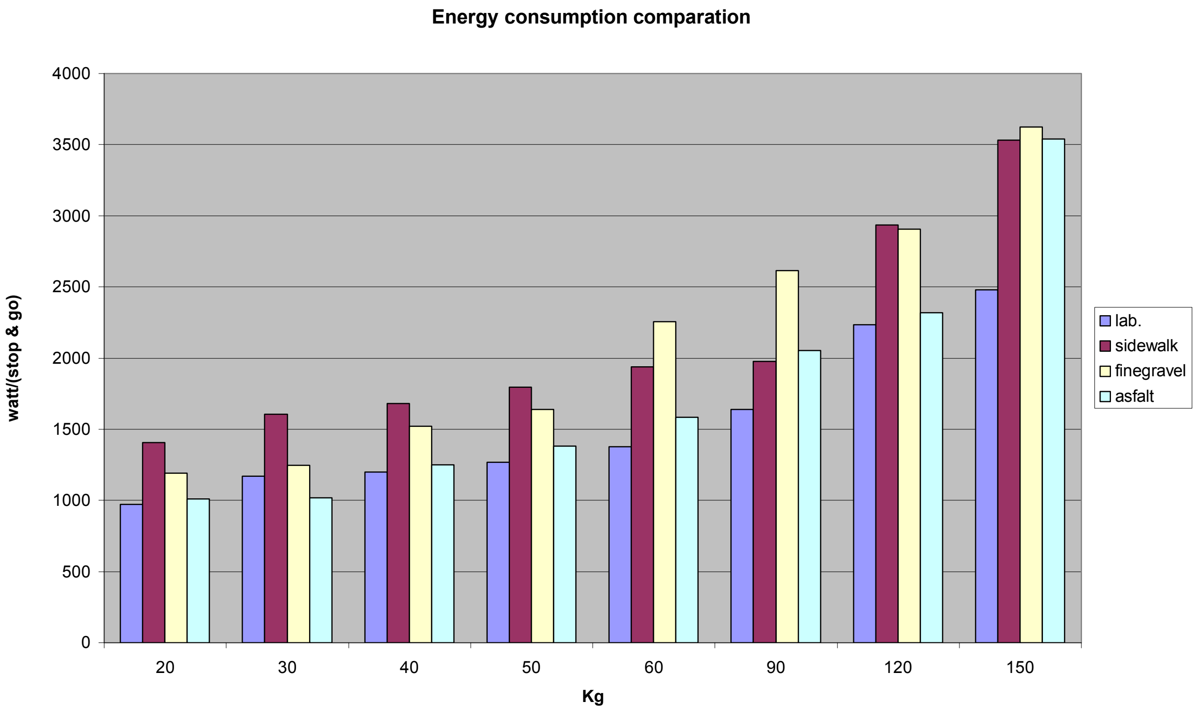


Table 2. Energy consumption by stop and go, and the payload.

The results obtained in the comparison of every test show different consumptions. Depending on the weight and the underground type the differences are more significant. When the weights are smaller, the differences are larger. However, when the weight reaches the maximum value, all the results obtained were similar.

Afterwards with the graphics of each test obtained with Fluke scope meter we realized the difference between a sportive or economic way of driving. The consumption of the caddy in a sportive driving increase rather by dint of a pick of energy consumption when the caddy is dropped suddenly.

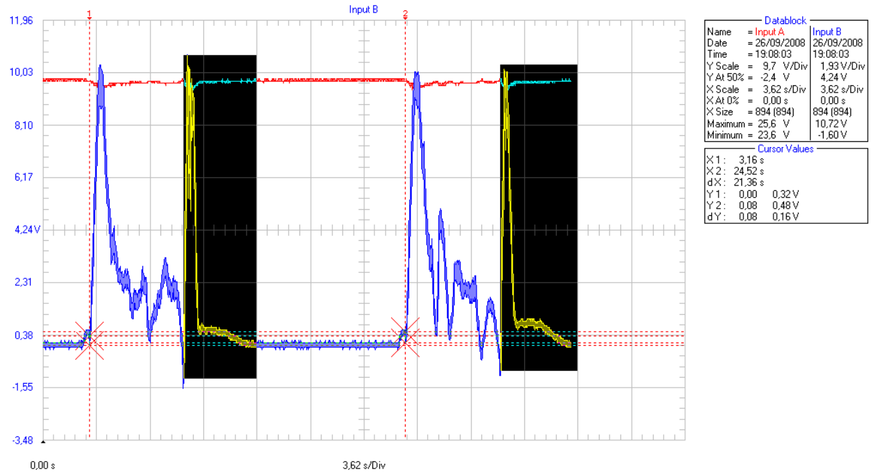


Figure 11.Fluke ScopeMeter test graphic.

This graphic shows two cycles of stop and go test. The last part of each cycle is the consumption that the caddy uses to brake the caddy.

The data acquisition system shows an error in the current measurements due to the influence of the weather conditions on the acquisition system. The current observed on the graphics was below zero notwithstanding applying an equation in excel (derib) and the problem was fixed.

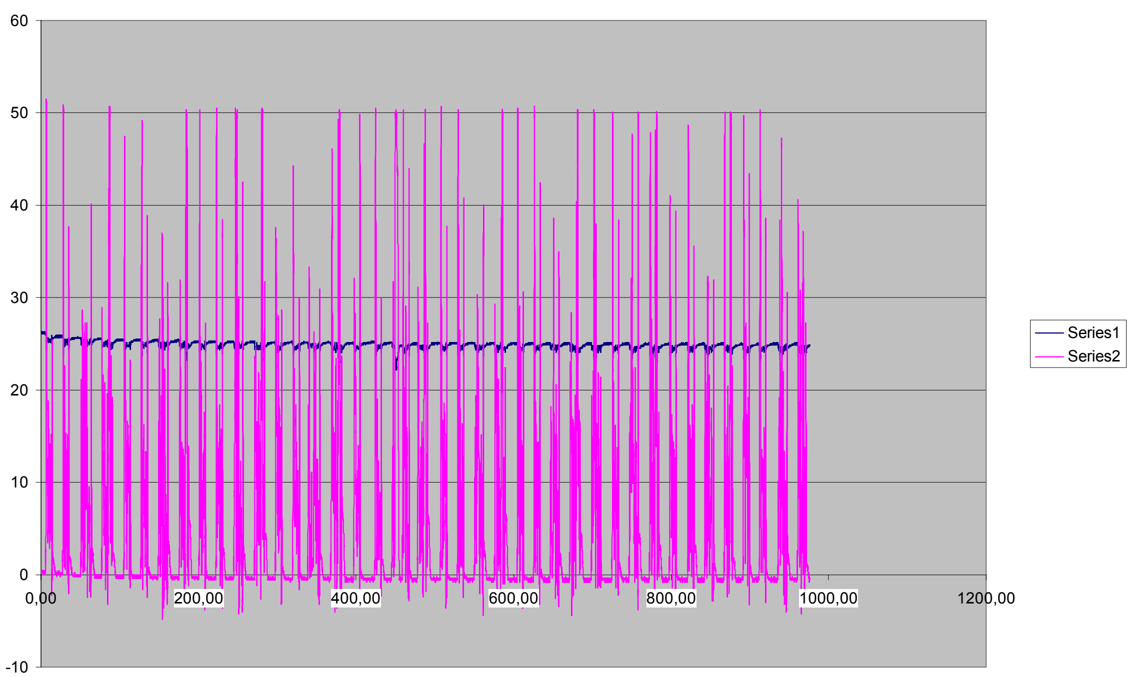


Figure 12. Current and voltage consumption.

This is an example of the current and the voltage.

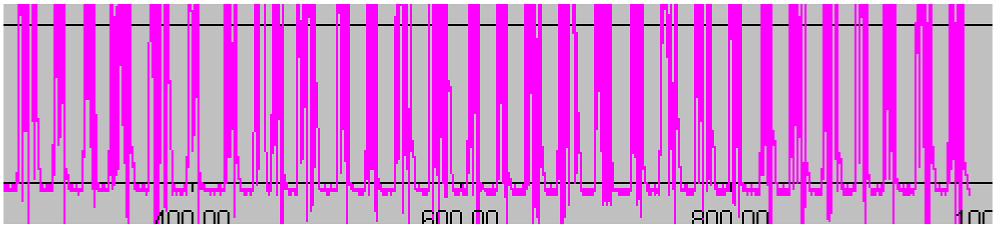


Figure 13. Error in measurement current.

This graphic shows the current measurement under the zero line.

4.3. *New measuring equipment.*

At the beginning, the communication with the caddy was simple. All the data were obtained by the Fluke scope. The problem was that we could not obtain the energy consumption based on the current and the voltage. (…….)

The data saved on the scope was immediately sent to the computer by usb cable with IR technology.

The problem with this measuring equipment was the fact that we were not able to apply on the second part of the thesis "the simulation model", regarding to the consumption of the caddy.

Introducing in the computer some parameters such as: weight, underground and stop and go. It is possible to calculate the energy consumption estimation. The aim of this simulation model is the estimation of the consumption of the caddy as realistic as possible.

Afterwards, new equipment was implemented on the caddy with a new data acquisition system to improve the measurements and to bring off the simulation model. Regarding the data acquisition system:

The data acquisition system can be used for any hybrid or electrical drivetrain architectures and for off- and on-road data logging. It retrieves the necessary parameters to assess the power flow control algorithm of the vehicle under test. It is a based on a National Instruments cRIO™ data acquisition system. (DAQ)

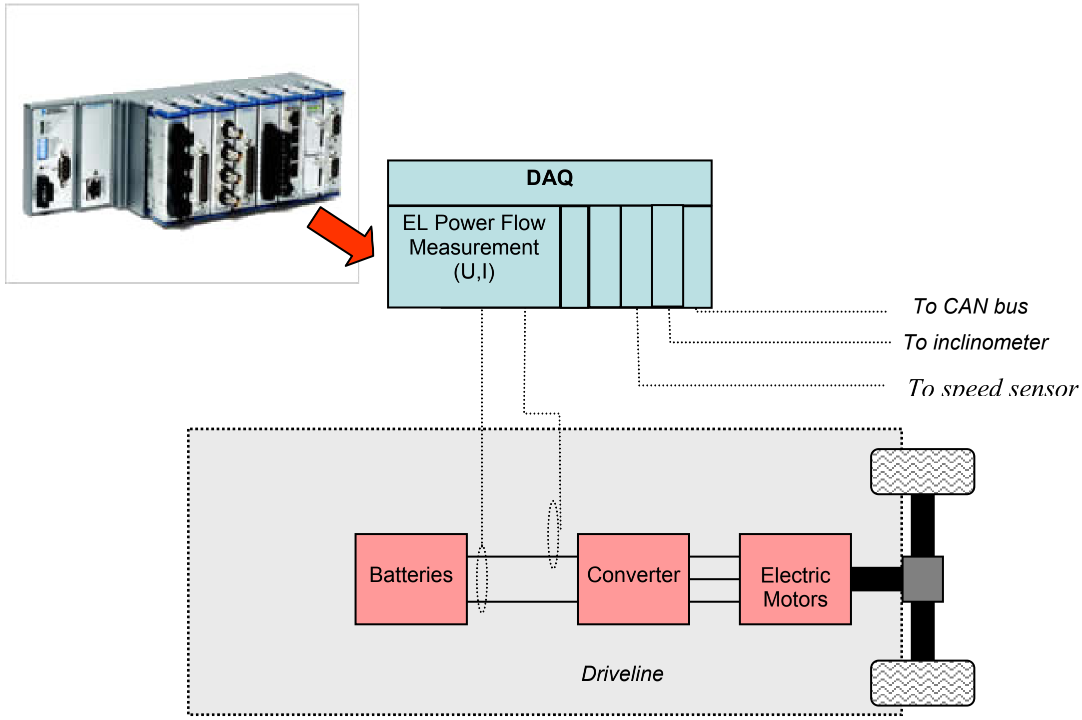


Figure 14. [3]

The DAQ consists of a chassis containing an embedded real-time processor and a reconfigurable FPGA. Different types of modules can be plugged in the chassis in order to measure different types of parameters. The FPGA offers the possibility to monitor several parameters simultaneously.
The processor is programmed with Labview and the retrieved data are stored on the DAQ during the measurement. After the measurement the data are downloaded on a PC.,

In the case of our caddy following parameters are monitored

Battery Current using LEM
Battery voltage using LEM
CAN-bus (speed in RPM)
Inclination, via seismic mass sensor of Gemac
Speed via DLS1 of Datron

`

4.3.1. Communication interface

The programming language used for this measurement equipment is the NI Labview. Labview is a program used by the new equipment which includes two parts: front panel (Figure 7)and block diagram (Figure 8,9). On the front panel the user introduce the different parameters values. The block diagram is designed depending of the aims and needs of the program. The programs that were built in this part of the thesis to obtain a communication between the caddy(current, voltage, time, slope and speed) and a controller (host computer or cRIO controller).

The first step after building the communication interface, is to make a program in which is possible to obtain the different parameters of each test. Furthermore, by this new equipment it can bring off the speed by the speed sensor. In addition, it is possible to obtain the speed from the CAN-bus of the caddy. In spite of the fact that the speed sensor works is better use the speed from the CAN-bus to do the calculations due to it is more exactly.

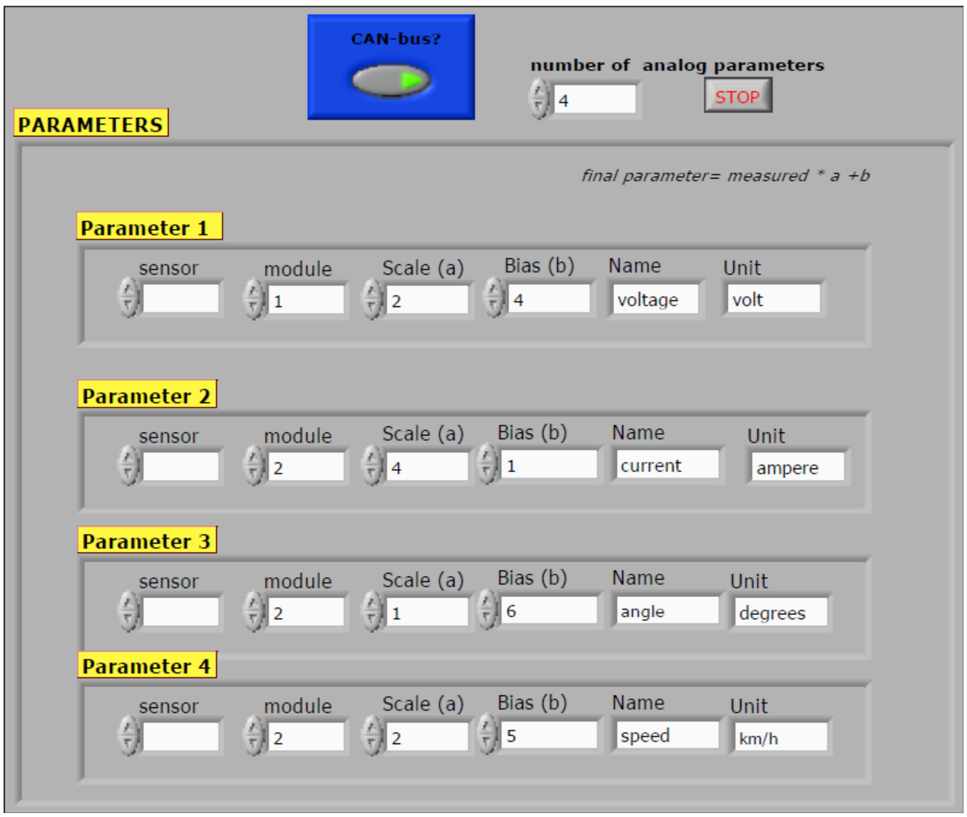


Figure 15. Block diagram, Lab-view program.

The block diagram is shown in the following Figure 9. It consists in a table which it is possible to watch the value of the different parameters. There are four parameters: the voltage, current, slope and the speed. In spite of the fact that it is possible to obtain the speed by the sensor, it is more exactly to obtain from the CAN-bus. According to this, it is necessary to implement another parameter on the block diagram. This program works until the user pushes the button "*STOP*" in the Front panel.

Before each test, the port is configured to can establish the communication to bring off information.

The next figures explain the software of the program "Lab view" implemented by Thierry Coosemans.

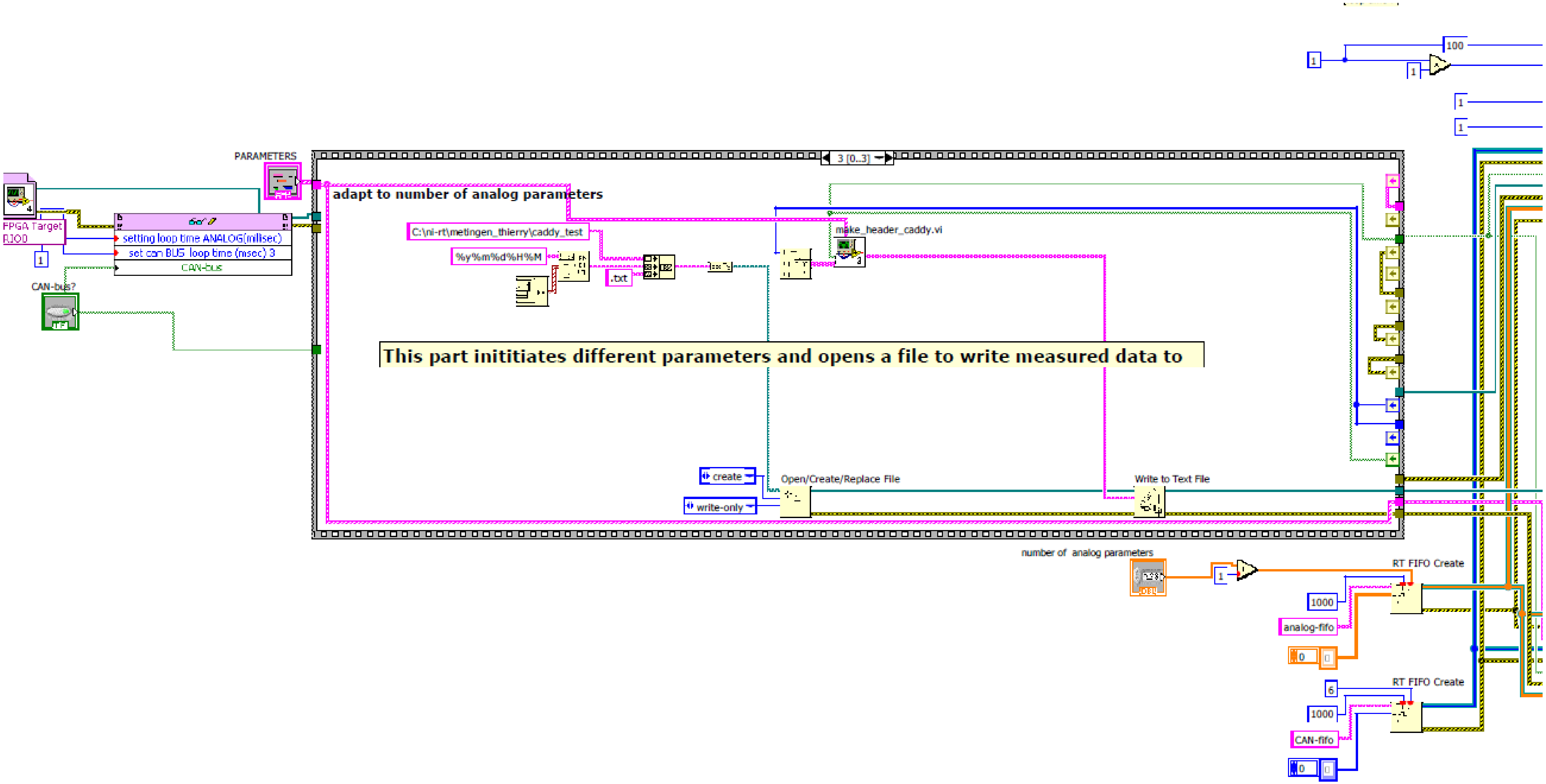
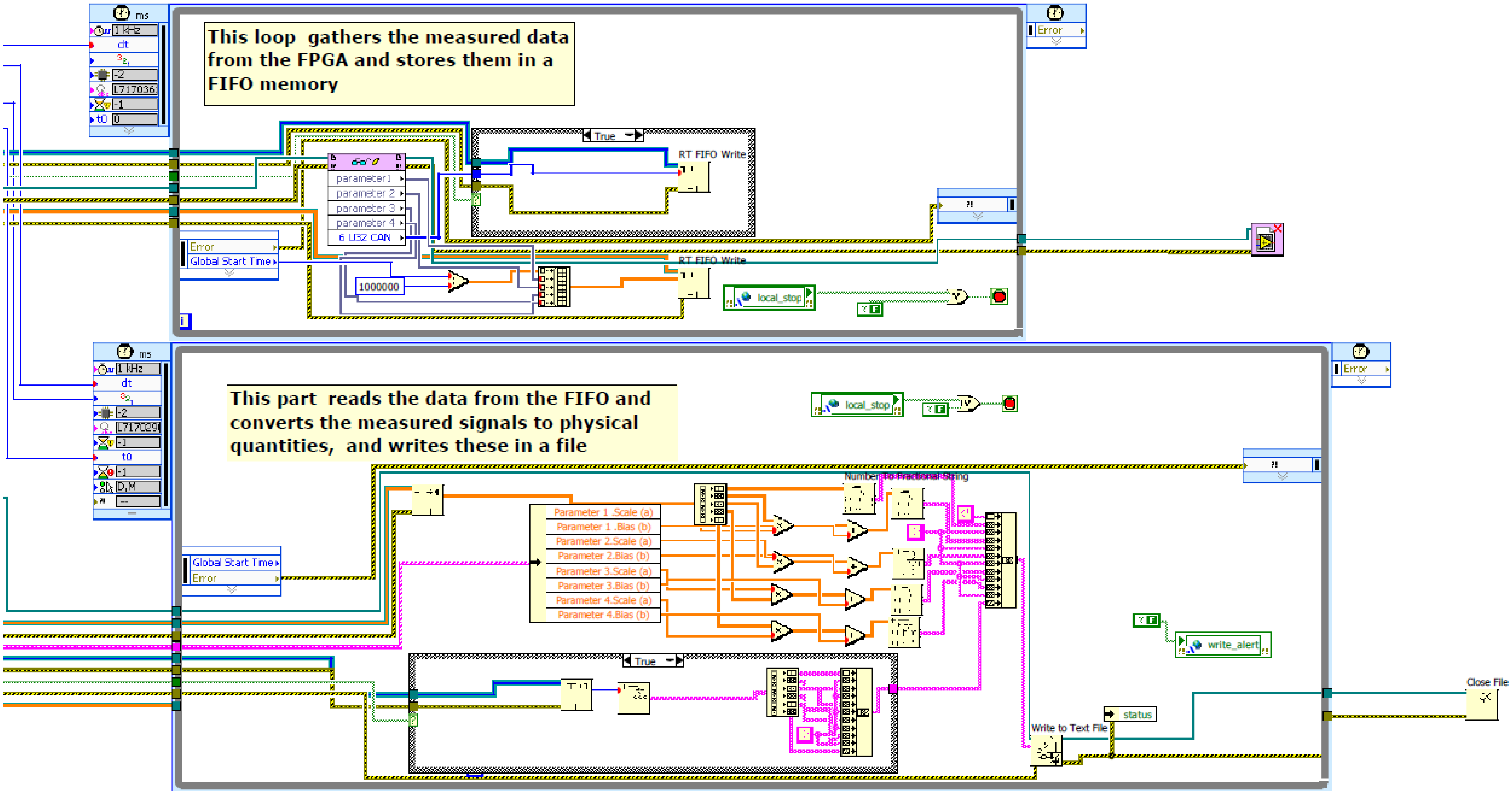
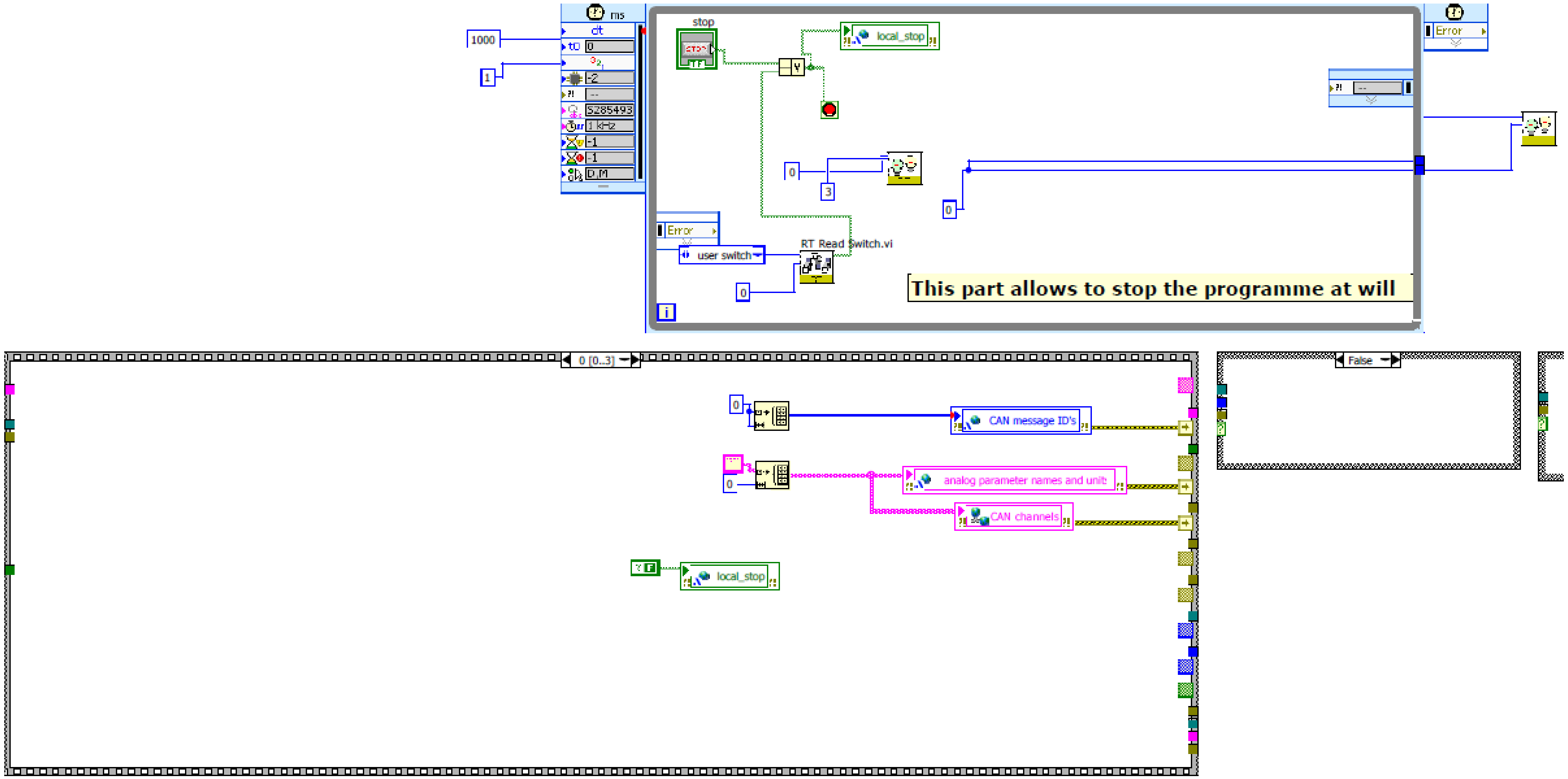

PARAMETERS
FPGA Target
RIO0
setting loop time ANALOG(millisec)
set can BUS loop time (msec) 3
CAN-bus
CAN-bus?
3 [0..3]
adapt to number of analog parameters
C:\ni-rt\metingen_thierry\caddy_test
%y%m%d%H%M
.txt
make_header_caddy.vi
This part inititiates different parameters and opens a file to write measured data to
create
write-only
Open/Create/Replace File
Write to Text File
100
number of analog parameters
RT FIFO Create
1000
analog-fifo
RT FIFO Create
1000
CAN-fifo

Figure 16



This loop gathers the measured data from the FPGA and stores them in a FIFO memory
ms
1 kHz
dt
Error
Global Start Time
parameter 1
parameter 2
parameter 3
parameter 4
6 U32 CAN
1000000
True
RT FIFO Write
RT FIFO Write
local_stop
This part reads the data from the FIFO and converts the measured signals to physical quantities, and writes these in a file
local_stop
Parameter 1 .Scale (a)
Parameter 1 .Bias (b)
Parameter 2.Scale (a)
Parameter 2.Bias (b)
Parameter 3.Scale (a)
Parameter 3.Bias (b)
Parameter 4.Scale (a)
Parameter 4.Bias (b)
Number To Fractional String
write_alert
status
Write to Text File
Close File
True

Figure 17



1000
1
ms
dt
stop
local_stop
RT Read Switch.vi
user switch
Error
This part allows to stop the programme at will
0 [0..3]
False
CAN message ID's
analog parameter names and units
CAN channels
local_stop

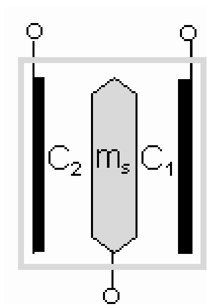
Figure 18

4.4. New sensors

4.4.1. The inclination sensor

Principle of measurement: Capacitive

The inclination measurement is based on the determination of the gravitation component gn=g *sin(a), which work on a seismic mass during inclinations out of the vertical position.[4]
The seismic mass is suspended from springs, so that the gravity component produced a movement of the mass. This movement is detected by electrodes with capacitive working principles.



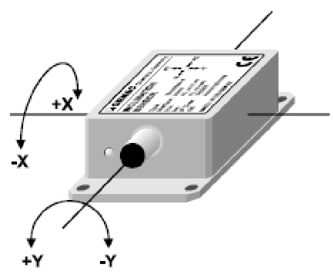


Figure 19.[4]

Figure 20.Inclination sensor[3].

4.4.2. The speed sensor

The measuring object is illuminated by a beam of light of a lamp (12 V/20 Watt) with a certain range of wavelengths. In fact, the lens system produces an image of the object and focuses this into the plane of a grating.[5]

A movement of the sensor of the surface causes a movement of structure points on the grating. From this a modulation is produced on the surface of the two photo receivers.

The frequency corresponding to the stationary sensor with a reference signal transmitter and supplied to the electronic evaluation as a reference and control variable for the motor speed.
The true-signed speed is determined from the difference between the measured and the reference frequencies.

Figure 21.Speed sensor.[5]

The problem with this sensor is the quality of the signal at low speeds, which is not really accurate, that is the reason why the speed analyzed to get the efficiency of the drive train is obtained by the Cam-bus.

4.4.3. Results from new measuring equipment

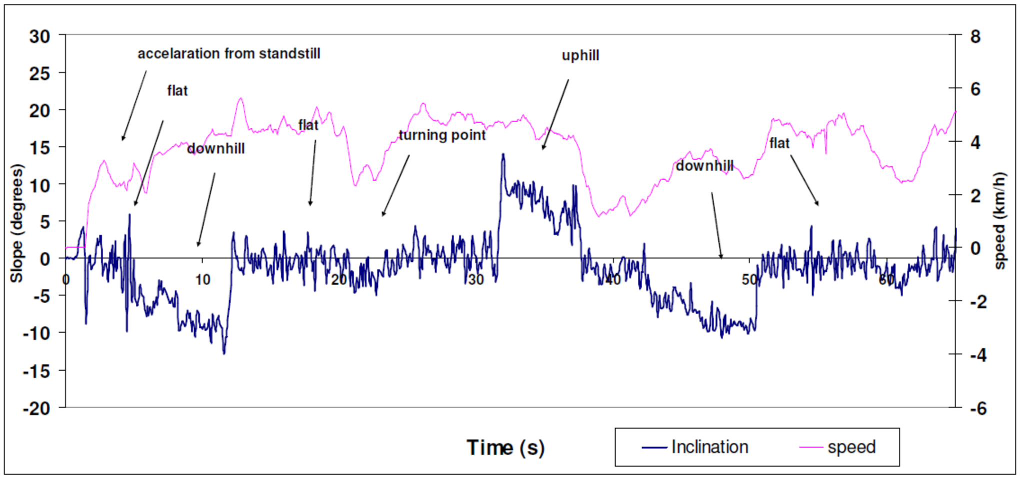


Figure 22. [6].

This plot shows the comparison between vehicle inclination, speed and battery current as a function of time.

At last, the speed of the wheels is obtained by the CAN-bus to calculate the efficiency of the drive train. The speed measured by rpm is introduced in the simulation model to obtain the efficiency and later bring off the energy consumption.

4.5. First conclusions

From the test results, it can be observed that there is a significant difference in the energy consumption depending on the kind of surface. The fine gravel and the sidewalk surfaces are the scenarios where more energy is consumed. On the contrary, the flat concrete surface (e.g. the laboratory ground) is the underground where the caddy consumes less energy.

The payload is together with the underground type the most important parameters on the energy consumption of the caddy. When the payload exceeds 100 kg, the energy consumption goes up quickly.
The plots show an increase of energy consumption up to 29% with a sportive driving.

The rolling resistance coefficient also has a marked influence on the consumption since it is the factor that models the friction force. Besides, it can be influenced by external factors such as the weather. For instance, a wet surface opposes a different friction force than a dry surface and these facts are reflected on the final energy consumption of the caddy.

The mentioned caddy tests are used to study the performance and efficiency of the vehicle under different surfaces, payloads and driving patters. These results, especially the ones concerning the drivetrain efficiency, are used to estimate the energy consumption of the caddy with a simulation software that is presented in (2.2).

A data acquisition system, based on National Instruments hardware, that is being developed at ETEC [6] was used in order to obtain all the time dependant variables such as, caddy speed, road slope and battery voltage and current. Several tests were developed and they proved and validated this measurement equipment, which will be later used to measure variables in real buses.

5. Simulation model

5.1. Introduction

Previous results obtained will be used to define a simulation model, the most important part of the project. This is the last part of the project and the final aim. The idea, based on the simulation of the energy consumption of the bikes, is to obtain a consumption value as realistic as possible.

Companies need a reliable tool to predict the energy consumption of the caddy depending on different parameters. By the moment, there are not extensive studies related where results and performance of the caddy will be predicted by a simulation model

The simulation model structure is the same used for the NPEH project but changing the values of some parameters like rolling resistance coefficient, payload number of start and stops and the drive train global efficiency. Using this simulation model is possible to obtain a calculation of the energy consumption of the caddy. Using the tests made previously with the Fluke scope meter we are able to compare the simulation results with the real values. Afterwards, is necessary to adjust the parameters depending on the types of surfaces and payload to achieve good values and at the end a useful simulation model.

The way to adjust the simulation model is to compare the real values with the calculate data of the consumption. Finally, the success of the project is to achieve similar results as the tests made before.

5.2. Efficiency

The first problem was how to reach certain efficiency. The way to calculate the efficiency of the caddy is the relation between the energy obtained directly from the batteries and the energy on the wheels.

Finally the difficulties to obtain the exact energy value on the wheels lead us to measure the energy of the drive train instead. The drive train (2.2) consists on sensors, converter, two electric motors and the wheels axle. There are several parameters which have influence on the efficiency. One of the most important parameters is the rolling resistance coefficient which is defined by the underground type.

5.3. Underground influence

Using the studies made before with the Fluke scope meter we realized that the influence of the underground kind is really important. However, to understand what it is happening in real, is better to apply the equation of the rolling resistance force.

$$Fr = m.g.c_{rr}$$

Equation 2

The c_{rr} is the rolling resistance coefficient, g is the gravity and $m.$ is the total weight of the caddy (weight of the caddy and the payload). The influence of the underground type is significant due to the rolling resistance coefficient. This parameter depends on the underground. There are several studies about this parameter; nevertheless, the real value is very difficult to obtain due to the irregularities of the terrain.

According to this, the value must be adjusted manually. At the same time the calculations must be changed and compared with the tests, the tests made by the Fluke scope before.

5.3.1. Way of driving influence

There are different ways of driving so it depends of each driver. Drivers have different ways of driving so it affects on the energy consumption. On the graphics downloaded from the Fluke scope to the computer, it released that in a sportive driving the caddy consumed more than if the person drive the caddy in a softly way.

When the caddy is dropped fast the inertia force is bigger than if the person drop the caddy softly. In that case the graphic show a really large pick current consumption at the end of each test. This effect (explained before 4.2) is difficult to measure exactly because of each time is different. There are not enough tests made in a heavy driving and softly driving so it's difficult to obtain results by now.

5.3.2. Different efficiency values

The studies made with the bicycles; show that the efficiency at constant speed is higher than the stop and go. The efficiency graphics about the caddy show that the efficiency decreases when the acceleration grows up. By this problem when there are many stops and go on the route the drive train global efficiency decreases.

The simulation model contents two different efficiency values. By now there are not results about the difference between two kinds of efficiency for the caddy. The program used to bring off the drive train global efficiency of the caddy, is Mat lab.

5.3.3. Mathematical procedure

By means of summation of forces it is possible to obtain the total force. There are different forces on the movement of the caddy: the potential force, friction force and the total force.

By physics equations it is able to bring off the total force and afterwards to this achieve the total energy consumed on the drive train. The energy from the batteries is easier to obtain due to it is directly obtained from the batteries.

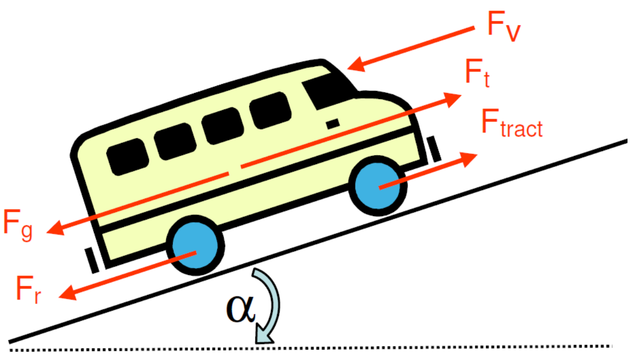


Figure 23.

$$\sum F = M.a = Ft - Fr - F\alpha$$ Equation 3.1

$$Fr = M.g.c_{rr}$$ Equation 6.2

$$F\alpha = M.g.\sin(\alpha)$$ Equation 3.3

$$Ft = M.a - Fr - F\alpha$$ Equation 3.4

$$Pt = Ft.v$$ Equation 3.5

$$Et_{wheels} = \int_0^t Ptdt$$ Equation 3.6

$$Et_{batteries} = \int_0^t V.idt$$ Equation 3.7

$$\eta_{drivetrain} = \frac{Et_{wheels}}{Et_{batteries}}$$ Equation 3.8

M =Weight of the caddy add the payload.
c_{rr} = Rolling resistance coefficient.
Fr = Rolling resistance force.
$F\alpha$ =Potential force.
Ft = Total force.
Pt = Total power.
Et_{wheels} = Total energy.
$Et_{batteries}$ = Total energy from the batteries.
$\eta_{drivetrain}$ = Drive train global efficiency.

The wind force is not important because of the speed of the caddy is really low (Max. 5 or 6 Km/h).

The rolling resistance force depends on the rolling resistance coefficient marked by the underground type. Each kind of underground has different value. This parameter is difficult to know exactly due to it depends on the underground and the surface of the wheels. There are several rolling resistance coefficient values for cars and for special bikes however there are not for a vehicle like the caddy.

The potential force depends on the height climbed by the caddy; each one is an input on the summation of the heights. When the caddy goes down this potential energy is not used.

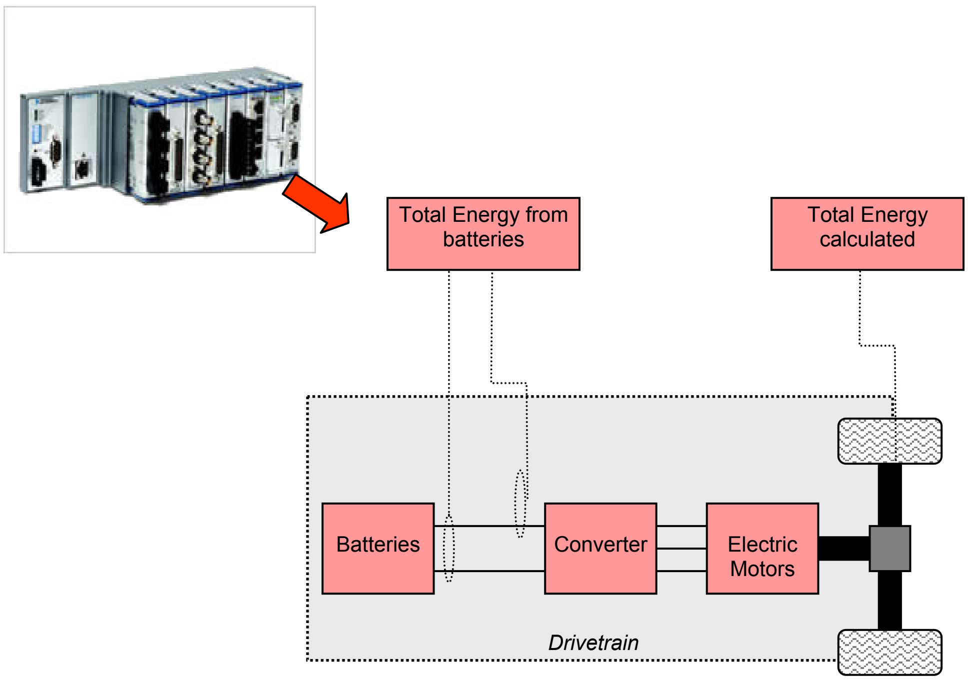


Figure 24.[6]

The difference between total energy on the wheels and the energy from the batteries is the drive train global efficiency. Afterwards each test, the data is download from the caddy computer (National Instruments cRIO™ **)** to the desk computer. Afterwards the test is checked personally to pass it.
All the data received is introduced on the simulation model made with Matlab program. This model made to bring off the drive train global efficiency needs several inputs:

- The time (seconds).
- The current (amps).
- The voltage (volts).
- The speed of the wheels (rpm).
- Specific rolling resistance coefficient.
- The payload.

5.3.4. Simulation model for drive train global efficiency

After bring off all the mathematic equations, the second part is obtain the drive train global efficiency calculations. Using a simulation it is possible to obtain the efficiency. Introducing different parameters and equations (5.3.3), we obtain the drive train global efficiency.

The program used is the Matlab. Next, I will explain this simulation model used to bring off the efficiency.

According to this, the follow pages show the simulation model using Matlab program. The first part is the global schema of the simulation. On the left side there are the inputs and on the right side there are the outputs.

All the inputs received by the data acquisition system are introduced to the simulation furthermore the values are transformed on the subsystem. The subsystem is formed by all the equations to transform the data. In this part is obtained the calculations witch is used to obtain the last results.

The simulation has two kinds of outputs. On one hand, there are the estimated calculations, using the speed and the forces, and the and on the other hand, there are the real calculations with the current and the voltage.

Afterwards the data are showed by graphics on the scope. The scope shows the speed, acceleration, power, energy and finally the global drive train efficiency.

Following all the explications, every graphics have two kinds of curves. The estimated calculations by the simulation furthermore the real calculations obtained by the real data. The power and the energy on the wheels are estimated calculations however the power and energy from the batteries are the calculations using the real values.

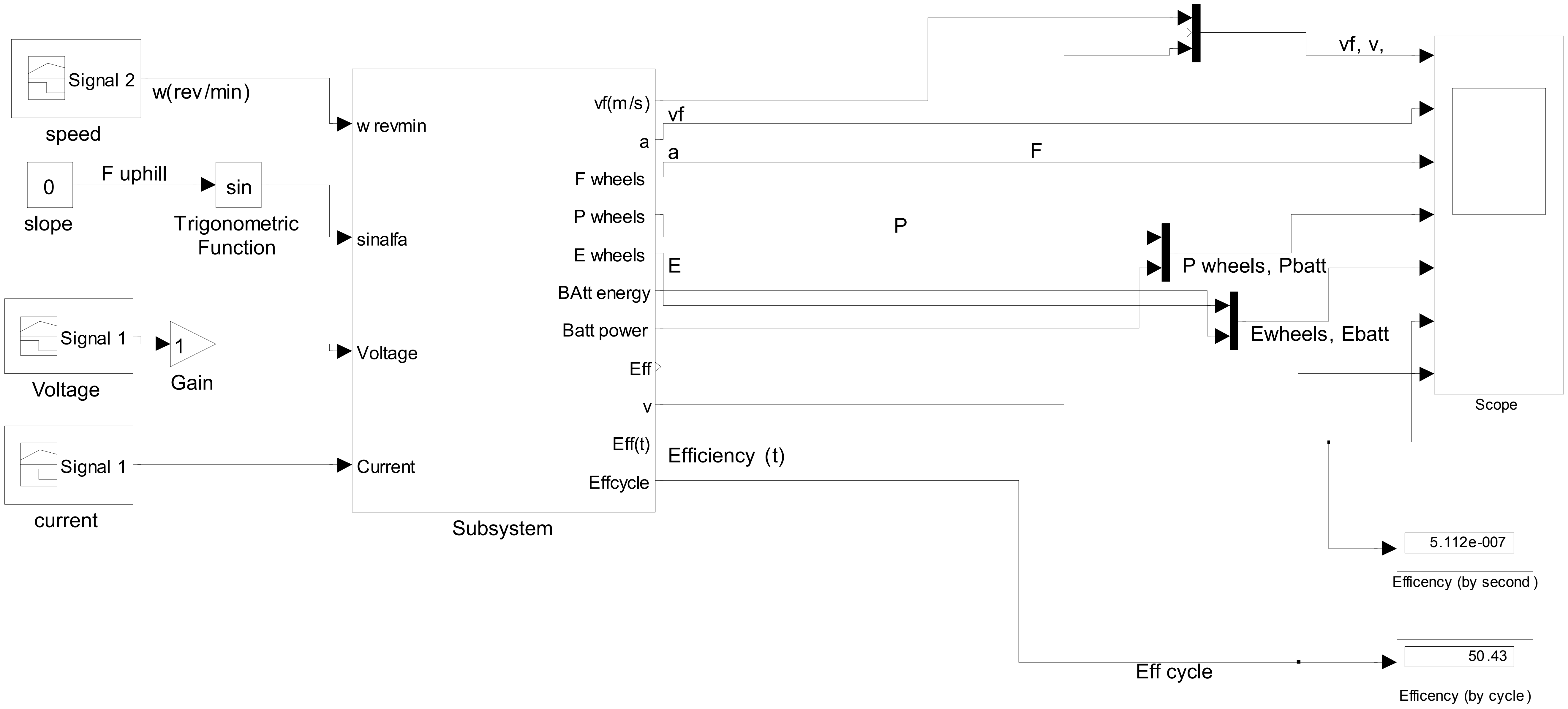


Figure 25.Efficiency simulation model, Mat Lab program.

Subsystem (under the mask)

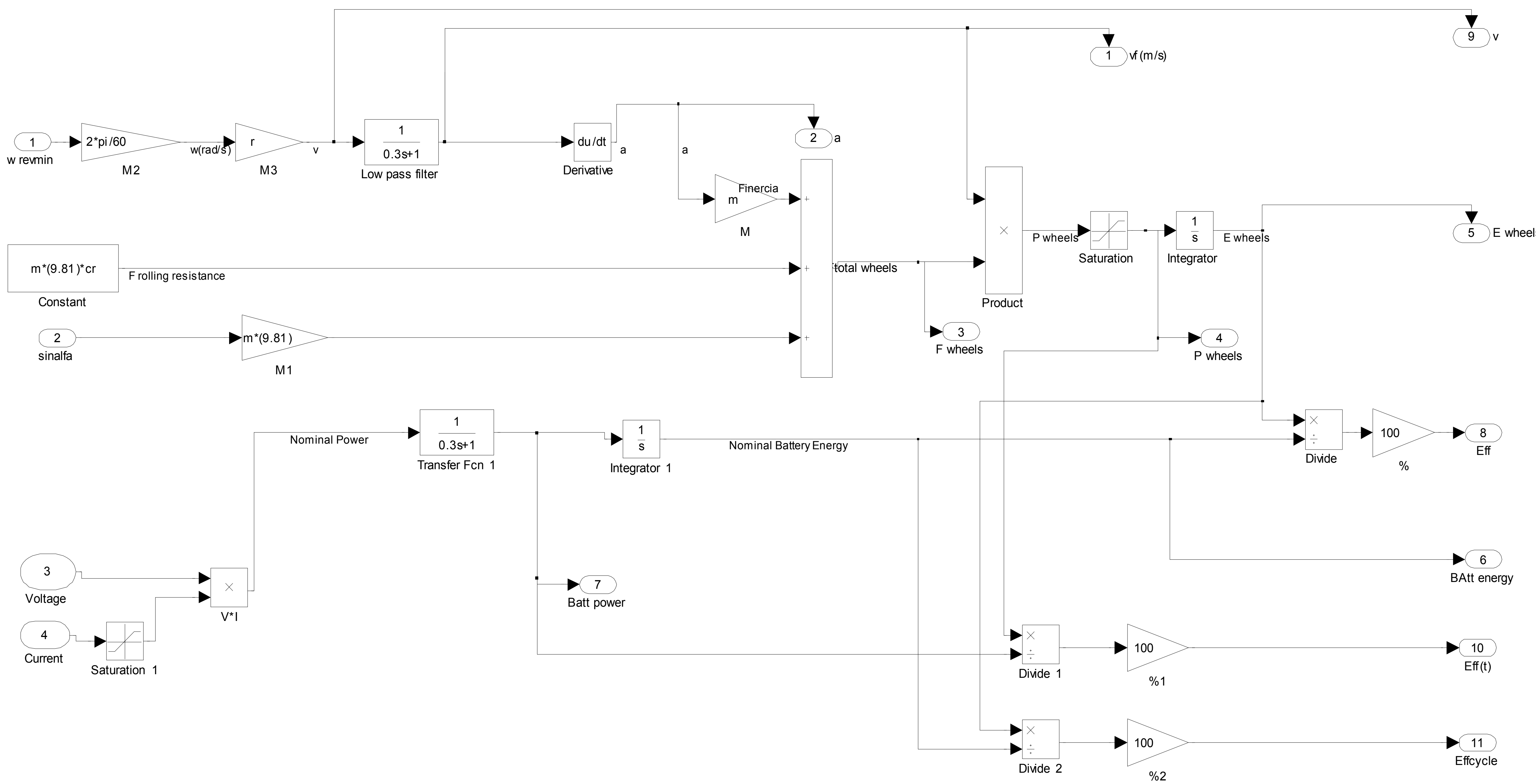
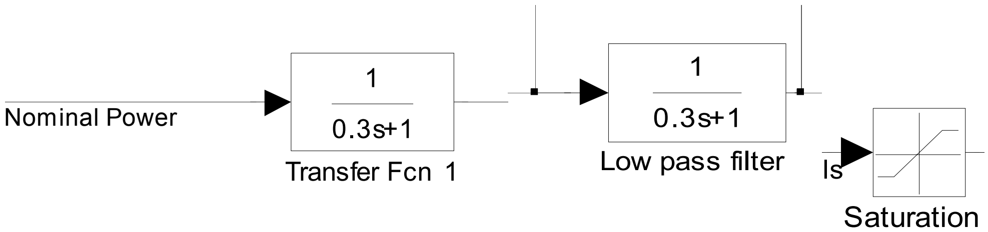


Figure 26.Subsystem explanation


Nominal Power
1
0.3s+1
Transfer Fcn 1
1
0.3s+1
Low pass filter
Is
Saturation

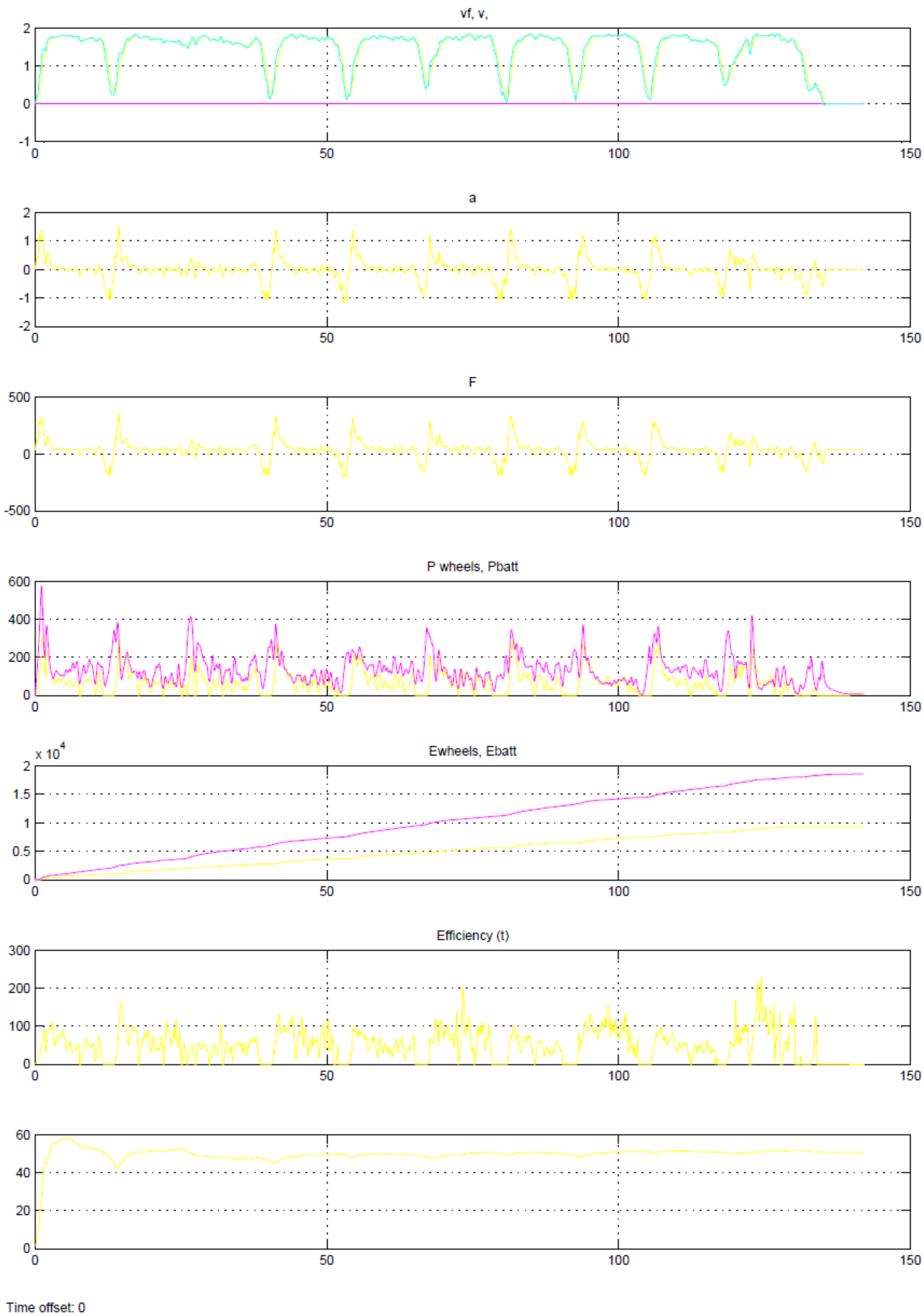


Table 3. Graphics of speed(m/s),acceleration(m/s2),Power(W/s), Energy(J) and Efficiency.

On the graphic [table 3], it can observe the difference between the estimated calculations and the calculations using real values. The blue color represents the real values and the yellow, the estimates values.

Throughout the graphics, the last two graphics represent the drive train global efficiency. Thus, the first one represents the efficiency by the time in seconds and the second one represents the efficiency of the whole test.

The efficiency by the time is higher than 100%, however this is due to the fact that the measuring equip has sometimes error by the noise on the signal, and therefore fluctuations in our estimated calculations. Nevertheless, the efficiency of the whole test is always lower than 60%.

This test for instance, is a constant speed test. This drive train global efficiency is obtained using normal values of the parameters, such as: rolling resistance coefficient, payload. The rest of the parameters are obtained directly from the DAQ (Data acquisition system).We can confirm that our simulation results are correct since the results obtained were consistent with our theoretical predictions.

5.4. Validation of the simulation model

Once obtained the efficiency, it is possible to start to work with the simulation model. The estimation of every parameter is the last part to obtain a correct simulation.

First of all, is important to know that the simulation model of the caddy is based on the simulation model of the bicycles. However, it is necessary to change parameters such as rolling resistance coefficient or efficiency.

The rolling resistance has been selected depending on the underground type. Nevertheless, it has been changed to adjust the final calculations. At the same time, the efficiency has been also changed to obtain more exact approximation.

The idea was to obtain good results using the same efficiency values for every underground type. However, it was necessary adjust the different efficiency values: constant speed and stop and go. The constant speed value was obtained using the simulation model for the efficiency and the stop and go efficiency has been selected with an approximation of the bicycles value. It is due to the fact that there are not enough tests with the caddy to obtain a concluded validation.

The procedure to adjust the simulation model consist on change these values and at the same time compare with the real values. For this operation, we created a new table in Excel to make the calculations easier.

The efficiency values selected were 55% for constant speed and 40% for stop and go. The first value was obtained by the simulation model to bring off the drive train global efficiency (see 5.3.4).

The rolling resistance coefficient has been estimated for the caddy. There are several values for the cars. Nevertheless in this case, the surface of contact of the wheels is lower than the cars. According to this, the coefficient for the caddy is lower than the cars'.

Once it is adjusted the rolling resistance coefficient, is adjusted each underground type following the same way.

The first problem to adjust the simulation was the consumption with heavy payloads. In case of flat concrete, asphalt and the sidewalk, when the payload is higher than 90 kg, the consumption grows up really fast. Except in case of the fine gravel, the consumption grows up faster from 120 kg. According to this, the values from the simulation in comparison with real data would be really different.

However, the problem with the consumption with heavy payload has to be fixed by another adjustment. If the efficiency values are changed when the consumption of the caddy grows up faster, the problem will be fixed.

Regarding the efficiency, the real values show higher consumption values than the simulation model for the heavy payloads. To solve this, it is necessary to take lower efficiency values.
Finally, we can say that the efficiency value is the same for every underground type. This is due to the fact that it is not really useful changing so many parameters to obtain the estimation of the consumption. On one hand, the fact to use the same efficiency value for every underground type is more adequate but, on the other hand, is true the fact that if the efficiency values would be different for each surface, the final results would have been quite similar.

The next table shows part of the simulation model. The most important parameters of the simulation are in red color. The first one is the payload; the values of this parameter go from 20 to 150 kg. The second input parameters are the distance and the number of stops (the distance is in meters). The third parameter is the rolling resistance coefficient which is depending on the underground type. The values for this parameter are the following:

- Flat concrete, 0.01.(table 5)
- Fine gravel, 0.016.(table 6)
- Side walk, 0.019.(table 7)
- Asphalt, 0.015.(table 8)

The next parameter is the drive train global efficiency. This value is the same for every surface with the goal of achieving a useful and easier simulation. It only changes with the weight. The value of the efficiency is 55% (constant speed) and 40% (stop and go). These values are from 20 to 120 kilograms. The value of the efficiency changes to 40% (constant speed) and 35% (at stop and go) from 120 to 150. These values are the same on every surface except on fine gravel, in this surface the efficiency value changes from 60 to 150 kilograms. The last part of the simulation shows the final energy consumption calculated.

NEPH design model

Input parameters

description	symbol	unit	
Power requierments			
payload	Mp	*kg*	*150*
vehicle mass	Mv	*kg*	*150*
driver mass	Md	*kg*	*0*
battery mass	Mb	*kg*	*0*
motor mass (+controller)	Mm	*kg*	*0*
Total Vehicle Mass (inc. Driver)	**M**	**kg**	**300**
(Top) speed	**V**	**km/h**	**5**
Speed between 2 stops	**Vb**	**km/h**	**5**
vehicle acceleration	**A**	**m/s2**	
Road inclination	**RI**	**%**	
Slow speed assistance	**SSA**	**%**	100%
Assistance factor	**AF**	**%**	**100%**
Range requierments			
cummulated hight difference	**h**	**m**	**0**
Total trip lenght	**D**	**km**	**0,4**
Nr of stops	**stops**	**#**	**40**

Summary of Results

Motor required mech. power	**Pm-m**	**W**	
Req. Battery capacity	**C**	**Ah**	**1,1**

Other input parameters			
Rolling friction coefficient	fr	-	0,0100
Aerodynamic drag coefficient	Cx	-	0,53
Frontal surface	S	m^2	1
transmission ratio (motor-wheel)	n	-	1,0
Wheel diameter	d	m	0,4064
Transmission efficiciency	Tran-Eff	%	94,0%
Motor efficiency (incl. Conv)	Mot-Eff	%	40,0%
Motor efficiency at low speed (incl. Conv)			**35%**
pedal gear efficiency	Gear-Eff		
pedal gear ratio	i		
Battery efficiency	Bat-Eff	%	70%
Battery voltage	Vbat	V	24
Constants			
Gravitation constant	g	m/s^2	9,81
Air density	ρ	kg/m^3	1,23
Wheel radius	r	m	0,20
Calculation results			
Wheel rotational speed	w	rad/s	6,8

Wheel rotational speed	v	rpm	65
Pedal frequency	v-ped	rpm	
Motor rotational speed	w-mot	rad/s	7
Motor rotational speed	v-mot	rpm	65
Road slope angle	α	rad	0,00
hight difference	h	m	**0,00**
Veh. Acceleration force	**Fa**	N	0
Veh. Rolling resistance	**Fr**	N	**29,43**
Veh. Aerodynamic drag (at V)	**Fcx**	N	0,63
Veh. Aerodynamic drag (at Vb)	Fcx-b	N	0,21
Veh. Slope resistance	**Fs**	N	0
Veh. Max Slope resistance	Fsm	N	0
Veh. Tot required force	F tot	N	
torque at wheel	Tw-tot	Nm	
force on pedal	Fp	N	
Veh. Driving resistance (on flat road at top spead)	Fd	N	30
Veh. Driving power (on flat road at top speed)	Pd	W	42
Wheel acceleration torque	Tw-a	Nm	0,0
Wheel rolling resistive torque	Tw-r	Nm	6,0
Wheel Aerodynamic resistive torque	Tw-cx	Nm	0,1
Wheel Slope resistive torque	Tw-s	Nm	0,0
Wheel Max slope resistive torque	Tw-sm	Nm	0,0
Wheel Tot. Torque	Tw-tot	Nm	6,1
Wheel Tot. Torque at max speed and flat road	Tw-tot2	Nm	6,1
Motor acceleration torque	Tm-a	Nm	0,0
Motor rolling resistive torque	Tm-r	Nm	6,4
Motor Aerodynamic resistive torque	Tm-cx	Nm	0,1
Motor Slope resistive torque	Tm-s	Nm	0,0
Motor Tot. Torque	Tm-tot	Nm	
Driver Torque	Tdriver	Nm	
Drivers MAX force on pedal	Fdriver max	daN	
Motor Tot. Torque2	Tm-tot2	Nm	6,5
Motor mechanical power	**Pm-m**	W	
Power needed from the battery	**Pe-b**	W	
Verliezen			
Motor mech. Power at max speed and flat road	**Pm-m**	**W**	**44**
Battery required elec power	Pb-e	W	111
Req. Mech. Energy for height diff	Eh	Wh	**0,0**
Req. Mech. Energy for stop&go	Es	Wh	**3,2**
Req. Mech. Energy for stop&go SSA	*Es ssa*	*Wh*	***3,2***
Driving time	Time	h	0,1
Req. Mech. Power for flat road driving	Pr	W	42
Req. Mech. Energy for cte speed driving	Er	Wh	**3,3**

per kilometer		*Wh/km*	*8,3*
Tot. Req. Mech. Energy	Emech-tot	Wh	7
Tot. Req. Mech. Energy from motor	Emot-tot	Wh	7
Tot. Req. Energy from battery	Ebat-tot	Wh	**19**
Tot. Req. Energy from battery SSA			**19**
Req. Desgn. Energy of Battery pack	Edesign	Wh	**27**
Watt/sec.			**95933,11**

Table 4. Simulation model.

5.5. Results of the simulation model

At this point of the thesis, is the moment to show the results of the simulation model. The follow plots show the difference between the real energy consumption, obtained by the tests, and the calculated consumption obtained by the simulation. Each plot represents each underground type.

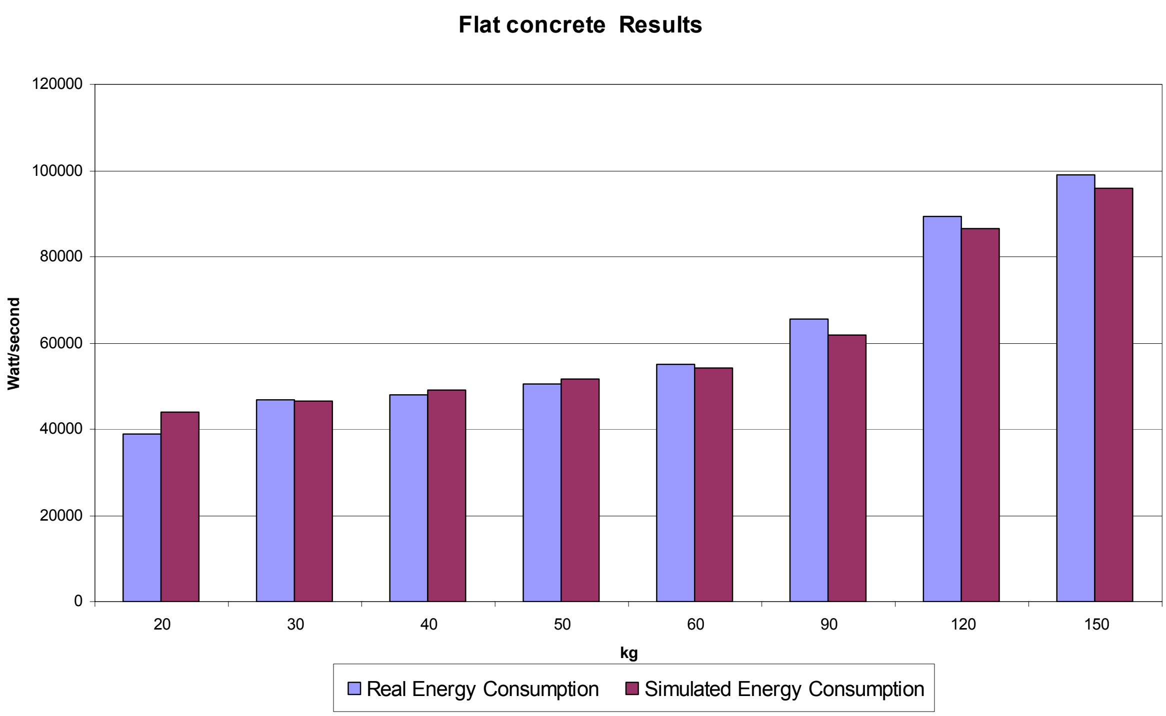


Table 5

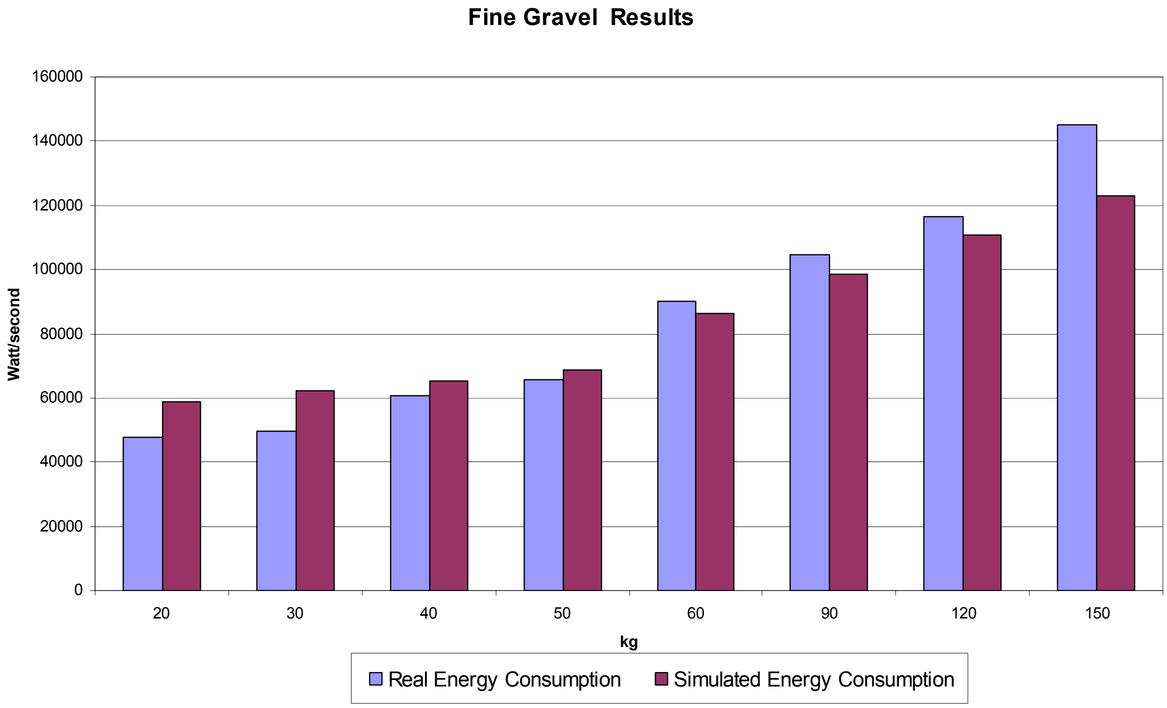


Table 6

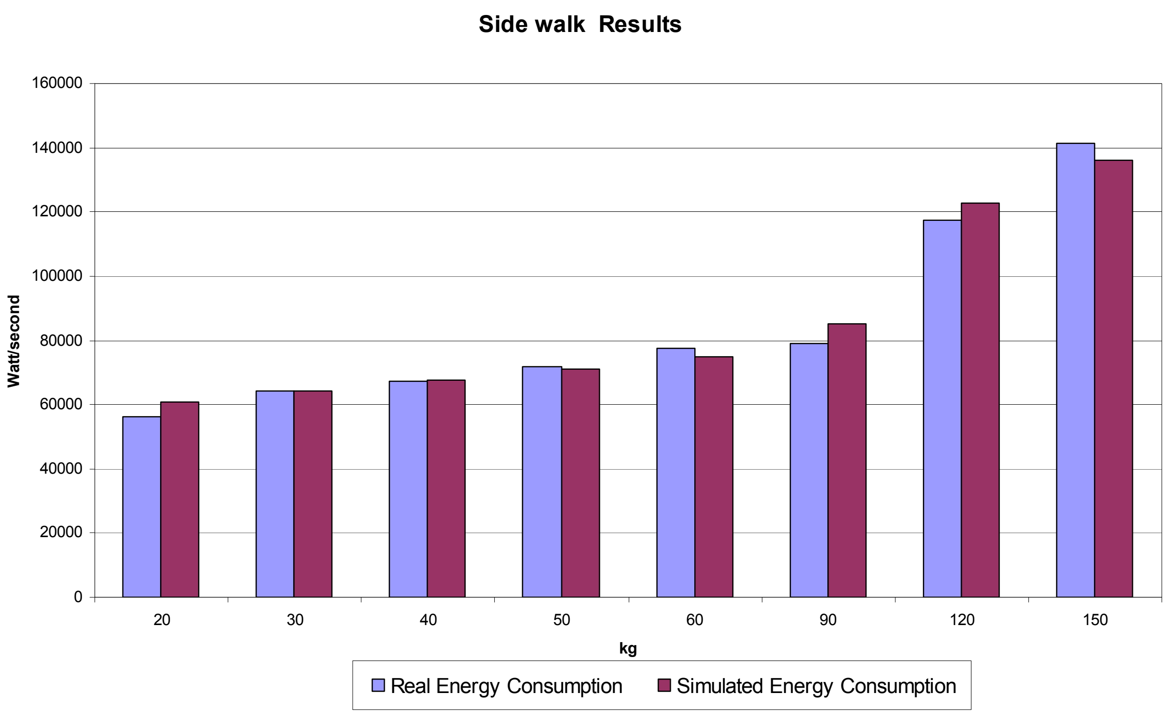


Table 7

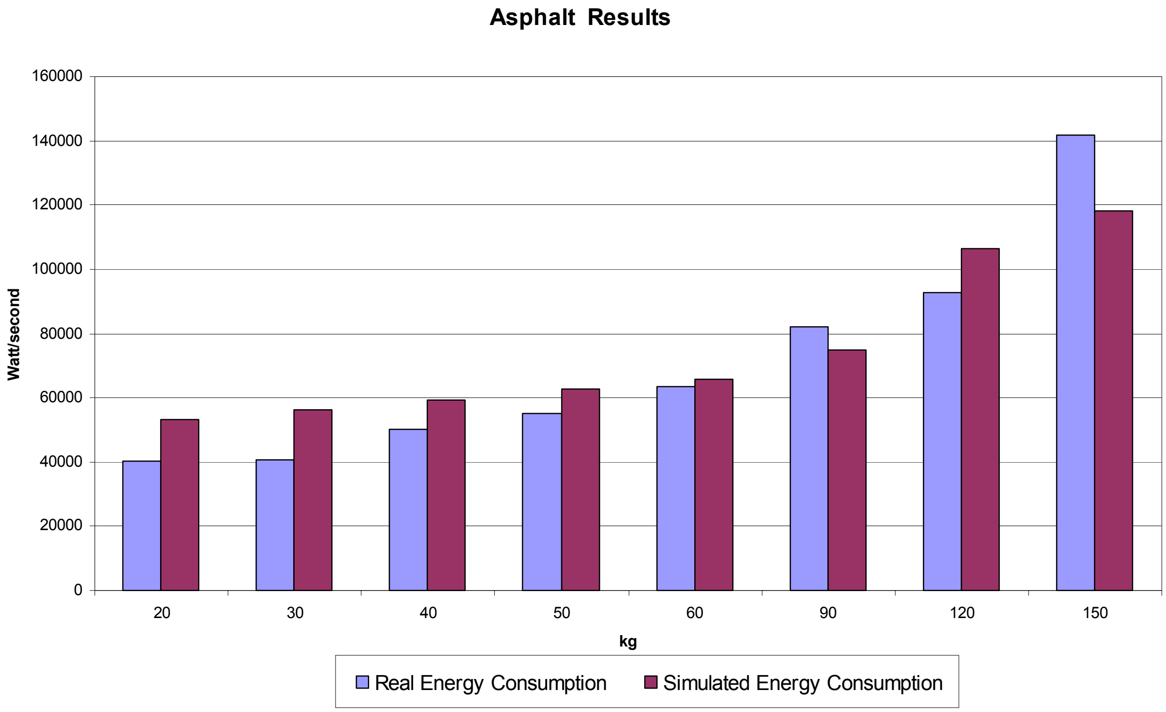


Table 8

The plots show several results to take into account. First of all, it is easy realize the data of the simulation and the data of the tests are really similar. However, there are several aspects to comment.

- It seems that the biggest differences on the consumption are at lowest and highest payload values. In addition, when the payload is between 20 and 40 kilograms on asphalt and fine gravel, the values of the simulation are higher than real values. Nevertheless, it is the opposite when the payload values are between 60 and 150 kilograms (only on flat concrete and fine gravel). On fine gravel and asphalt it oscillates between 90 and 120 kilograms.
- Nevertheless, on the sidewalk, the real values are lower than the simulation from 90 to 150 kilograms.
- Furthermore, the last test on asphalt is really large. However, this value is probably due to the measure equipment or a mistake on the test. Nevertheless, it has not been possible to repeat the test due to the problem with the caddy at the end of the thesis.
- With regard to the asphalt, the largest difference on the plots is from 20 to 30 kilograms. In these points, the simulation is not really effective. However, it was not possible repeat these test due to the same problem.
- On one hand, the best result of the simulation was obtained on the side walk with an error value of +8% and -4%, on the other hand, the largest difference was on asphalt with +38% and -16%. The +38% value corresponds with the two first values and -16% correspond with the last value of the test.

5.5.1. Future work

According to the results, the simulation works, however it can be improved.

- ✓ First of all, the problems with the caddy should be fixed to go on with the tests. Furthermore, there are some tests to repeat to improve the simulation results.
- ✓ Repeating the test with results not really reliable on the results of the simulation.
- ✓ Create an interface through [.....] to obtain the energy consumption of the simulation without using the excel table. Introducing only the underground type, number of stops, meters of route and the payload. The program receives the information and it calculates the energy consumption.
- ✓ Changing the efficiency value depending on the underground type could improve the final simulation results.
- ✓ There are not enough tests on slope. It would be useful to introduce on the simulation. In addition, the efficiency simulation made on Mat Lab, it is possible to enter into the program this parameter as another input.

5.5.2. General conclusions

The simulation results are changed depending on the underground type. At limit values, as much on highest as on lowest, results obtained are less accurate. To sum up, the most important aspects to take into account are the payload, the underground type and finally the influence of these parameters on the drive train global efficiency. Despite of the fact that certain values are not really correct, the simulation results are rather correct. There is work to do to adjust the simulation however it has not possible to me because of an error on the caddy at the end of the thesis.

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[1] "New Electric Postman Helper" NEPH Industrial meeting – Caddy October 30th, 2008 Vrije Universiteit Brussel - ETEC, Brussels
[2] Power density and energy density
[3] Bedienung_MagiCexpress. Expresso company.
[4] Feteris Components B.V.
[5] 2008 CORRSYS-DATRON Sensorsysteme GmbH, Wetzlar L-350_m-639-p1-e-rev001 10/08
[6] Data Acquisition System for Optimization of Series Hybrid Propulsion Systems.